State of California
DEPARTMENT OF TRANSPORTATION

Business, Transportation and Housing Agency

Memorandum

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To: MS. MEG SCANTLEBURY
Branch Chief, Special Projects
Office of Cultural Resource Studies

Date: June 14, 2009

File: 04-SF-101- Doyle Drive
04-163701
Vibration Levels Justification

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Subject: Doyle Drive – Recommended Construction Vibration Levels

Introduction

We are recommending that the allowable maximum construction vibration levels, at building locations, in the San Francisco Presidio be 0.3 inches per second (in/sec) peak particle velocity (PPV). In addition, we recommend PPV testing of each new piece of vibration inducing construction equipment and vibration monitoring at all buildings within 200 feet of construction.

The *Built-Environmental Treatment Plan* (August 2008) has suggested a limit of 0.08 in/sec PPV. Within the *Built-Environmental Treatment Plan* found those past standards, of 0.08 in/sec, were appropriate. The Treatment plan states *"....08 inch per second of peak particle velocity(PPV) at a 200-feet distance, was conservative but an appropriate limit to apply..."* This sentence has little meaning when analyzed. It is asking for a value of 0.08 in/sec at 200 feet, this is regardless of the distance of the structure it is tying to protect. The *Final Environmental Impact Statement (October 2008)* also suggest that the vibration of *"...0.08 in/sec is appropriate limit the historic buildings of masonry construction."* The report also suggests a limit of 0.2 in/sec for *"...wood-framed structures, which are less susceptible to damage."*

PPV follow a reverse log curve or an exponential scale, therefore values begin very high near the source and drop off rapidly the farther from the source. Soil condition has a damping effect on vibration. "*...Clays tend to exhibit higher damping than sandy soils (Wiss 1967). Wet sand attenuates less than dry sand because the combination of pore water and sand particles in wet sand does not subject compressional waves to as much* *attenuation by friction damping as does dry sand.*"[1] The curve in Figure 1 is an example of an attenuation curve. The top-bounding curve is an example of vibration through solid ground, such as rock or very condensed sand. The bottom-bounding curve is for soft or loose soils. Vibration should be measured adjacent to the structure being monitored. And appropriate values should be chosen based on known studies. Therefore the statement above is not reasonable. It does not establish any vibration values at the building locations. PPV attenuation curves also vary depending on geology at the site. This is why we would like to have a test at the beginning of the project for each new piece of vibration inducing equipment. We can develop the actual attenuation curves for individual pieces of equipment and the site geology. In addition, the value of 0.08 in/sec is a value that has been associated with continuous random vibration as opposed to random vibration due to single impact (such as pile driving) that we will discuss further in this memo.

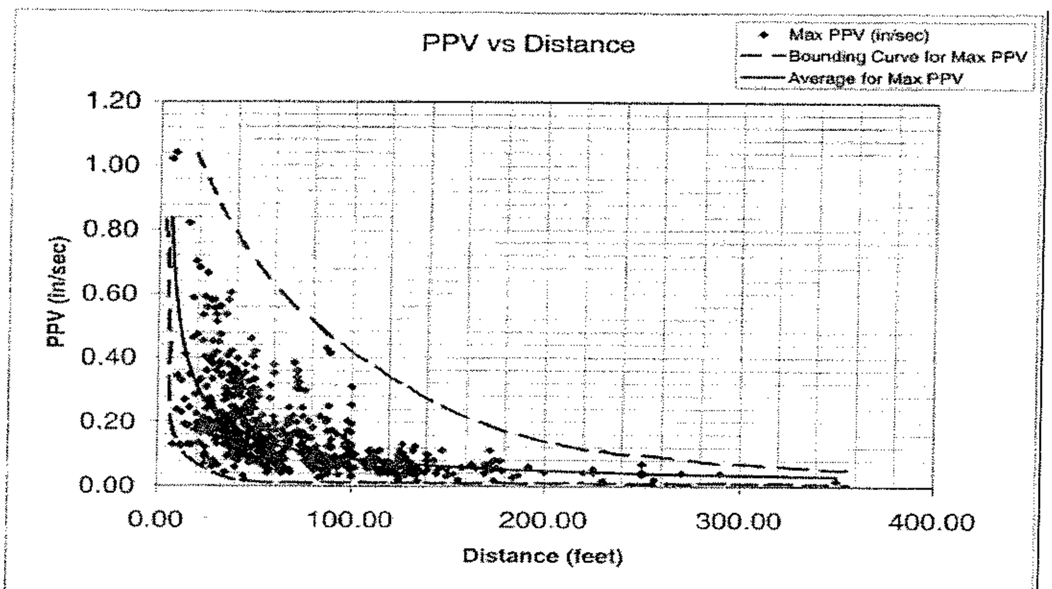

Figure 1 [2]
Attenuation Curve shows typical pile driving vibrations with distance, Data from PDCA Vibration Database.

[1]Jones & Stokes, 2004, Transportation- and Construction-Induced Vibration Guidance Manual California Department of Transportation Environmental Program Environmental Engineering Noise, Vibration, and Hazardous Waste Management Office

[2] Figure taken from California Department of Transportation Division of Environmental Analysis Office of Noise, Air Quality, and Hazardous Waste Management TRANSPORTATION RELATED EARTHBORNE VIBRATIONS Technical Advisory, February 20, 2002

Caltrans Policy

There are various types of construction vibration sources. Amick, Hal and Gendreau, Michael, in their 2000 paper, *Construction Vibrations and Their Impact on Vibration-Sensitive Facilities*, divided construction vibrations into four categories. These categories are:

- "*Continuous random vibration:* Vibrations may cover a wide frequency range. Most excavation and static compaction equipment falls into this category. Tracked vehicles are predominantly of this type, but may also exhibit characteristics of high-rate repeated impact due to the tracks hitting the ground.
- *Random vibration due to single impact or low-rate repeated impact:* This type of vibration results from the soil "ringing" due to sudden dynamic loading. It may include pile driving, blasting, the use of a drop ball, and a "pogo-stick" type of compactor.
- *High-rate repeated impact:* This is typified by the jackhammer, which generates vibrations at the frequency of impact (such as 19 Hz) and integer multiples of that rate (such as 38 Hz, 57 Hz, etc.)
- *Single-frequency continuous vibration:* The predominant sources of this type of vibration are vibratory pile driving, pile extraction, and vibratory compaction. They are similar to sinusoidal vibration."[3]

The most damaging vibration source is continuous random vibrations. Continuous random vibrations create a constant frequency, which can match the resonance frequency or natural frequency of a structure. When this occurs more energy is absorbed in the building, causing damage. In contrast, random vibrations due to single impact or low-rate repeated impact (such as pile driving) create vibrations that are short intervals and die out before the next interval can occur. This dying out of the vibration does not allow for the steady state frequency that will match the frequency of the structure, thus not allowing resonance and the consequential damage to occur.

The energy that is produced is most commonly measured in PPV. PPV is the maximum velocity attained by a wave during its lifetime.[4] In the past Caltrans has set limits to construction vibration a PPV of 0.4-0.6 in/sec.[5] This level was set due to research completed for single event vibration sources such as pile driving. The following are a list of some of the other research:

Table 1

[3] Amick, Hal and Gendreau, Michael, 2000, Construction Vibrations and Their Impact on Vibration-Sensitive Facilities, *San Mateo, California*

[4] ibid

[5] Hendriks, Rudy, 2004, Transportation Related Earth Borne Vibrations, Caltrans.

Source	Structure	Single Event Source PPV (in/sec)
Chae: Building Vibration Criteria Relatively[6]	Old residential structures in very poor condition	0.5
Dowding: Building Structure Vibration Criteria[7]	Historic and some old buildings	0.5
Swiss Association of Standardization Vibration Damage Criteria[8]	Class IV: construction very sensitive to vibration; objects of historic interest	0.3
Sedovic: Historical Architect[9]	Historic structures	0.5

It is also recommended we conduct an attenuation studies at the beginning of construction, for each piece of equipment to estimate PPV at the various structure along the project. These attenuation studies are site specific and are used to determine the dampening effect of the soil on the equipment. The results of the study will estimate PPV at a given distance away from the source.

Measured Vibration Levels along Doyle Drive

The Final Noise and Vibration Study and Caltrans both conducted background vibration measurements, in 2004 and 2009, respectively. The locations where the measurements are listed in Tables 1 and 2 below.

Table 2

Designation	Description
Location 1A	At the foundation base of the northwest corner of Building 201, approximately 8 m (27 ft) from the curb of Halleck Street and approximately 17 m (55 ft) from the nearest support column of Doyle Drive.
Location 1B	At the base of a southern support column of Doyle Drive, approximately 17 m (55 ft) north of Location 1a.
Location 2	At the foundation base of the northeast corner of Building 105, approximately 5 m (15 ft) from the curb of Lincoln Boulevard, immediately west of Doyle Drive.
Location 3	On the concrete curb of Washington Boulevard, directly over the top of the Park Presidio Tunnel.

Table 3

6 Chae, Y. S. 1978. Design of excavation blasts to prevent damage. *Civil Engineering—American Society of Civil Engineers* 48(4):77–79.
7 Dowding, C. H. 1985. *Blast vibration monitoring and control.* Prentice-Hall. Englewood Cliffs, NJ.
8 Wiss, J. F. 1981. Construction vibrations: state-of-the-art. *Journal of the Geotechnical Division* 107(GT2):167–181.
9 Sedovic, Walter, 1984, Assessing the Effect of Vibration on Historic Building

Caltrans Location	Date	Time
Northwest corner of Building 201	December 17, 2008	08:15 - 11:58
Southbound Bent 31R	December 17, 2008	12:40 - 16:41
Northeast corner of Building 105	December 18, 2008	07:00 - 12:00
Washington Boulevard, directly over the top of the Park Presidio Tunnel	December 18, 2008	12:16 - 16:16
Northwest corner of Building 683	December 19, 2008	8:00 – 11:59
Southwest corner of Building 650	December 19, 2008	13:04 – 17:01

(Locations are shown on Figure 1)

In the Final Noise and Vibration Study, vibration measurements were obtained and at Location 1B (a support column for Doyle Drive) the maximum PPV for a 15 minute time period was 0.09 in/sec.

Caltrans measurements are as follows, taken from January 14, 2009 Memorandum:

> *"...Bent 31R has the average maximum peak particle velocity of 0.025 in/sec, but the average high peak particle velocity at a historic structure is 0.012 in/sec, at building 201. Building 201 is an occupied wood framed wood sided commercial building located approximately 40 south of Marina Viaduct. The maximum peak particle velocity of 0.075 in/sec was located at building 650, which is a vacant wood framed stucco building within 20 feet of the High Viaduct Structure."*

The Noise and Vibration Study came back with measurements of 0.09 in/sec, and Caltrans recorded levels of 0.075 in/sec. Both of these PPV show that structures along Doyle Drive already experience the levels approaching and in some cases exceeding the proposed 0.08 in/sec.

Conclusion

Since the measured background PPV exceeds the proposed 0.08 in/sec limit, the vibration levels should be placed at a higher peak than 0.08 in/sec.

In addition, the PPV of 0.08 in/sec is arrived at from various sources was for *"...historic monuments in poor state of repair or buildings of historic interest*[10]*..."* and is based on a continuous random vibration source to prevent buildings from being damaged. A safe PPV level of 0.5 in/sec has been recommended by experts such as: Walter Sedocvic, a Historical Architect with North Atlantic Historic Preservation Center, Charles H.

[10] Wiss, J. F. 1981. Construction vibrations: state-of-the-art. *Journal of the Geotechnical Division* 107(GT2):167–181.

Dowding, Professor of Civil Engineering at McCormick School of Engineering and Applied Science Northwestern University, and Yong S. Chae, Professor of Civil Engineering, Rutgers University. Also the proposed type of construction (pile driving) will not produce continuous random vibration, but will produce random vibration due to single impact or low-rate repeated impact. This random vibration will cause less vibration and will not produce a frequency that will match the natural resonance frequency of buildings at the Presidio.

Therefore it is our opinion that the maximum PPV allowed can be raised from 0.08 in/sec. This PPV should be raised to suit the structures on site. Most of the structures onsite are in good condition, being either originally in good condition or have been retrofitted or have been, or currently being, upgraded by the Presidio. Buildings 106 and 228, which are in poor conditions or are close to the proposed construction, will be stabilized before construction begins. We therefore recommend that the maximum allowable PPV be increased to 0.3 in/sec measured at the building, in accordance with the Swiss Association of Standardization Vibration Damage Criteria (Table 1).

We feel that because Caltrans is stabilizing the buildings that appear to be structurally deficient, and the construction vibrations being produced will occur from a single impact or low-rate repeated impact that the level of 0.3 in/sec is justified for protecting buildings onsite.

If you have any questions or require further information, please contact Matthew Gaffney at (510) 622-1777 or Grant Wilcox at (510) 286-4835.

c: TPokrywka, GWilcox, MGaffney, Daily File, Route File, Translab File

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